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# A new suspension system for the measurement of magnetic susceptibility along different directions of anisotropic crystals with the help of Curie balance

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**Abstract** : At present, it is not possible to measure the magnetic susceptibilities along different directions of an anisotropic crystal by suspending it freely in a Curie balance. In the existing method, help of the measurement of anisotropy and/or magnetic susceptibility of powdered sample is needed. In doing so, two different experimental set-ups are necessary. In the present paper, a new suspension system has been described where the freely suspended crystal can be forced to align with any of its desired directions parallel to the magnetic field. Thus, the measurement of magnetic susceptibilities along different directions of the crystal is possible with only one experimental set-up.

**Keywords** : Magnetic susceptibility, new suspension system

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In an anisotrotic crystal, the three principal susceptibilities $\chi_1$, $\chi_2$ and $\chi_3$ cannot individually be measured by a Curie balance by suspending the crystal freely. The help of the measurement of anisotropy and/or magnetic susceptibility of powdered sample is needed.

It would be useful if the susceptibility could be measured along any direction we desire, especially along all three directions ($\chi_1$, $\chi_2$, $\chi_3$) with the help of one set-up only. The present work describes a method which achieves this.

Although there are other methods for measuring the three principal susceptibilities individually [1], but there the three principal directions must be known. It will be shown later that in the present method of suspension, it is sufficient if we know only one of the principal directions.

*Existing method of measurement of $\chi$ :*

The crystal is suspended from one arm of a micro-balance by a fibre (silk or quartz) along $\chi_1$ in a horizontal magnetic field having a gradient perpendicular to the direction of the field (Figure 1) [2]. The crystal in addition to setting itself with the direction of maximum susceptibility (say $\chi_2$ ) along $\boldsymbol{H}$, will experience a pull in the direction of the gradient of the

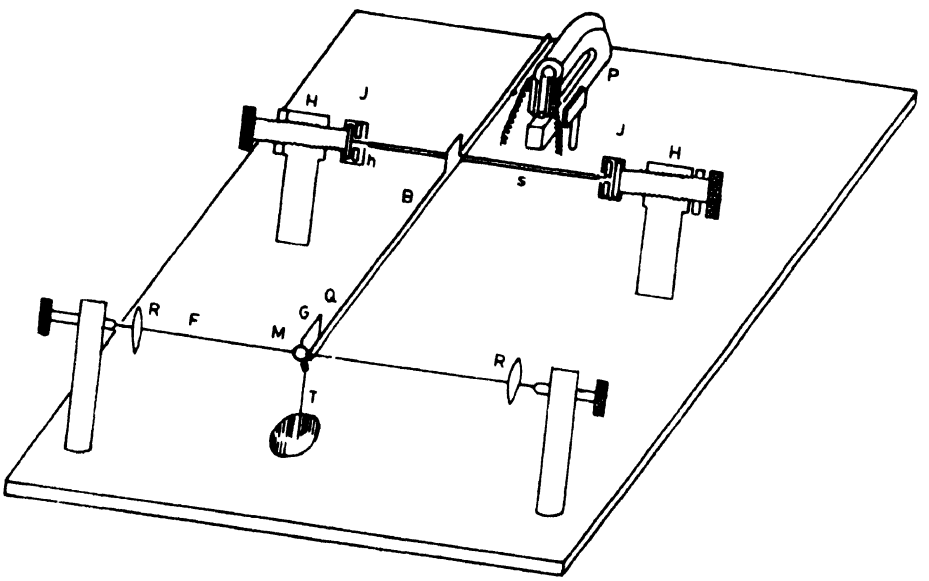


**Figure 1.** Schematic diagram of the microbalance (not to scale). *B*-Arm of the balance, *S*-stainless steel spindle, *J*, *J*-Jewels, *H*, *H*-Brass stands, *P*-Permanent magnet, *C*-Current bearing coil, *M*-Light plane mirror, *G*-pyrex glass rod, *Q*-Quartz fibre, *F*-Unspun silk fibre, *R*-*R*-Copper springs, *T*-Suspension system; *N*-Brass base of the balance..

field with a force proportional to $\chi_2$. Knowing the magnitude of this pull, $\chi_2$ can be determined. Since the freely suspended crystal will never set itself with the direction of minimum susceptibility along $\boldsymbol{H}$, it is not possible to make measurements along the direction of minimum susceptibility with this balance.

To determine $\chi_1$, $\chi_2$ and $\chi_3$, therefore we need two experimental set-ups.

I. A set-up for the measurement of $\chi$, with Curie balance.

II. A set-up for the measurement of anisotropy $\Delta\chi$ by Krishnan's method.

*Description of the new suspension system :*

The suspension system is shown in Figure 2 (a and b). In Figure 2(a), *A* and *B* are two teflon pieces cut in the form of squares having fine holes at the centres. A glass rod is inserted through the hole of *A* as shown in the figure and then fixed by araldite or dental cement. Through the hole of *B*, a glass capillary is inserted so that it does not go out of the other face, as shown in the figure. The size of the capillary should be such that the rod through *A* can pass through it and can be fixed by quick-fix or the like. *B* can be separated

from *A* by using a solvent (acetone *etc.*) which will not dissolve araldite or dental cement *etc*. With the help of a rotating head provided with a vernier scale, *B* can be rotated with respect to *A* and fixed in any position we desire. A very stable and highly anisotropic crystal

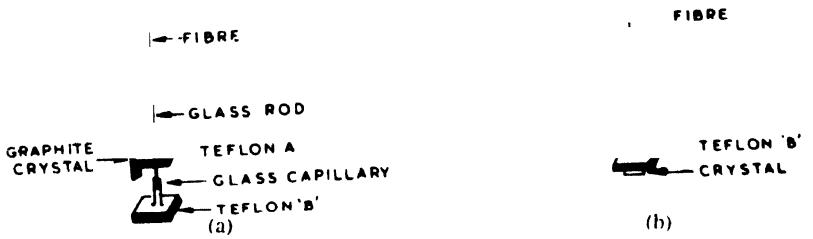


**Figure 2.** Suspension system

with large susceptibility along one direction will be necessary at this stage. We have chosen graphite a diamagnetic crystal for this purpose ($\chi_{\parallel} = -22.5 \times 10^{-6}$ cgs emu and $\chi_{\perp} = -0.5 \times 10^{-6}$ cgs emu). The graphite crystal is fixed on one side of the square teflon *A* (Figure 2a) so that when suspended, the basal plane of the graphite crystal remains vertical. When magnetic field is applied, the crystal sets itself with the basal plane parallel to the magnetic field.

The whole suspension system (teflon *A* + graphite + teflon *B*) is suspended in such a way that *B* lies at the centre of the region of the field gradient. With the magnetic field on, the current $C_1$ through the coil required to balance the pull on the suspended system is noted. This is repeated for different magnetic fields. A standard substance (for paramagnetic substance $Gd_2O_3$, and for diamagnetic substance KCl) whose magnetic susceptibility is known, is then suspended by a separate fibre in such a way that it lies in the same position of the gradient of the magnetic field as *B* of the aforesaid system. The balancing current corresponding to different magnetic fields is noted for the standard sample. The balancing system is now calibrated.

The crystal *s* whose susceptibility along a particular direction $a_1$ is required, is then fixed to one side of *B* so that $a_1$ lies in the horizontal plane. *B* is now rotated with respect to *A* in such a way that $a_1$ is parallel to the basal plane (*i.e.* $\perp$ to *c*-axis) of graphite.

The chosen graphite crystal should have sufficiently large mass with respect to that of the sample. The suspension system (A + B + graphite + sample s) when suspended in the magnetic field will then set itself with the basal plane of graphite parallel to the magnetic field *i.e.*, the direction of $a_1$ parallel to the magnetic field. With the magnetic field on, the current $C_2$ required to balance the pull is noted. Then $C_1 \pm C_2$ will give the values of balancing current ($i_s$) required for sample *s* only. Then the susceptibility $\chi_s$ in the direction $a_1$ is calculated using the equation

$$\chi_s = \chi_o \frac{i_s}{i_o} \times \frac{m_o}{m_s} \tag{1}$$

where $m_o$ – mass of standard sample,

$i_o$ – balancing current for standard sample,

$\chi_o$ – susceptibility of the standard sample,

$m_s$ – mass of the crystal,

$i_s$ – balancing current for crystal,

$\chi_s$ – susceptibility of crystal.

Then by rotating $B$, the orientation of the crystal $s$ is changed with respect to basal plane of graphite so that another direction say $a_2$ is now parallel to the magnetic field. This will enable us to measure the magnetic susceptibility of crystal $s$ along $a_2$. Similarly, the magnetic susceptibility of crystal $s$ can be determined in any direction.

*The advantage of the proposed method over the existing methods :*

The magnetic susceptibilities in all the directions can be determined with only one experimental set-up. A corrollary to this fact is that in case we can identify one of the crystallographic axes only, we can determine the principal susceptibility non-destructively along all three directions even if the susceptibility along the identified direction is not a maximum.

For testing the instrument we have taken a crystal $NiSO_4.7H_2O$, whose susceptibilities are known and the average susceptibility of the three principal directions are given at room temperature [3]. This sample is paramagnetic, so we have taken $Gd_2O_3$ as standard sample. The balancing current required for $Gd_2O_3$ at different magnetic fields were observed at room temperature. It has been observed that the susceptibility along the direction perpendicular to <010> plane is a minimum so if suspended freely, susceptibility along this direction can never be determined. $NiSO_4.7H_2O$ is fixed on $B$ (Figure 2a) in such a way that <010> direction of the crystal is perpendicular to the $c$-axis of graphite crystal and the whole system is suspended in the magnetic field gradient. The magnetic susceptibility $\chi_2$ is then calculated using eq. (1). To know the susceptibility in another direction *i.e.* $\chi_1$, the crystal is suspended freely *i.e.* without graphite by fixing the sample at the bottom of teflon $B$ so that <010> direction of the crystal is vertical (Figure 2b). The system is then suspended in the magnetic field gradient and the required balancing current are observed and then applying the eq. (1), $\chi_1$, the maximum susceptibility in the horizontal plane, is calculated. The values of $\chi_1$ and $\chi_2$ determined above along with the average value of susceptibilities given in reference [3] would give $\chi_3$.

We thus obtained (at room temperature) the following values :

$\chi_1 = 15.95 \times 10^{-6}$ cgs emu,

$\chi_2 = 14.89 \times 10^{-6}$ cgs emu,

$\chi_3 = 15.12 \times 10^{-6}$ cgs emu,

and these values are in good agreement with the values obtained by earlier worker [3].

So we see here that following this method of measurement, the crystal can be forced to remain aligned with the direction of minimum susceptibility parallel to the magnetic field. It has thus been possible to determine the minimum susceptibility of the crystal directly which has not been possible so far.

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